

BBC RD 1973/24



Engineering Research Report

The work covered by this report was undertaken by the BBC Research Department for the BBC and the IBA

A u.h.f. ruggedised log-periodic aerial

J.L. Riley, M.Sc.

A UHF RUGGEDISED LOG-PERIODIC AERIAL
J.L. Riley, M.Sc.

Summary

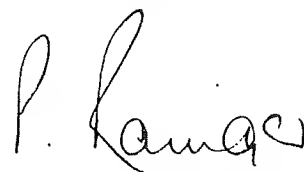
A ruggedised u.h.f. log-periodic aerial covering Bands IV and V and suitable for both receiving and transmitting purposes has been developed.

There are two versions of the aerial, one with an air-spaced main feeder boom and the other with a dielectric loading on the aerial boom.

Some of the more important design factors are described in detail. The side- and back-lobe radiation is more than 23 dB down on the main lobe at all frequencies. The aerial effective gain is about 8 dB relative to a half-wave dipole.

The aerial is suitable for production in large quantities and unit cost could be comparatively low.

Issued under the authority of



Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

October 1973
(RA-116)

A UHF RUGGEDISED LOG-PERIODIC AERIAL

Section	Title	Page
	Summary	Title Page
1.	Introduction	1
2.	Initial design	1
3.	Mechanical construction	2
4.	Further design considerations	2
	4.1. Boom taper	3
	4.2. Element length compensation	3
	4.3. Drive-point	3
	4.4. Dielectric loading	4
	4.5. Weather-proofing	5
5.	Measured performance	5
	5.1. Impedance match	5
	5.2. Radiation patterns	6
	5.3. Gain	6
6.	Conclusions and discussion	6
7.	References	7

A UHF RUGGEDISED LOG-PERIODIC AERIAL

J.L. Riley, M.Sc.

1. Introduction

A u.h.f. log-periodic receiving aerial was originally developed by Research Department¹ and has formed the basis of design for commercial aërials intended for the domestic market. Basically, it is a wideband aerial with very good side- and back-lobe suppression and which is capable of working in either E- or H-plane.

Subsequently requests have arisen for a ruggedised version of the log-periodic aerial for professional application. There were two immediate areas of interest.

Firstly, a wideband aerial appears attractive to the field strength measuring teams who at present employ three separate yagi aërials to cover the u.h.f. bands. The need to change continually from one aerial to another and the added awkwardness of altering their polarisation means that a single aerial to fulfil the same role would save engineers' time and effort.

Secondly, the transmitting aërials currently proposed for low-power u.h.f. relay stations are of the 2λ panel type, three versions being required to cover the u.h.f. bands. These perform satisfactorily and aërials can be tiered and arrayed to produce a multi-element aerial with numerous variations in radiation pattern. There are two possible advantages of a log-periodic array provided it is capable of producing similar patterns to the panel array or patterns equally acceptable. These are:

- (i) a saving in costs by having only one basic aerial unit to manufacture, store and erect,
- (ii) a saving in mast structure cost as the windloading capacity of the log-periodic array is considered to be less than the equivalent panel array.

The basic requirements of a receiving aerial and a transmitting aerial are different, the former being primarily concerned with directivity and low side- and back-lobe radiation levels whereas the latter is governed more by matching considerations. It was, however, the intention of the work described in this report to examine the possibility of producing an aerial to fulfil both these requirements and to develop such an aerial for broadcast use. In addition, the aerial must of necessity be made rugged, weatherproof and reliable.

Two versions of the aerial have emerged from the work carried out although both are capable of performing the same function. The second version is proposed as an alternative to provide a greater degree of weather protection.

2. Initial design

The log-periodic aerial consists of an array of linear

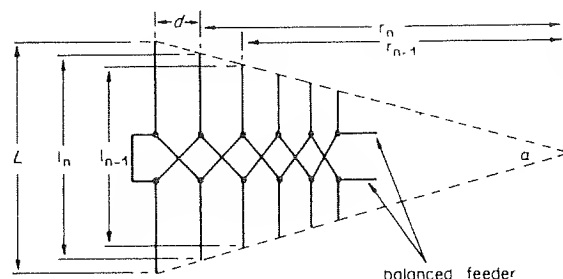


Fig. 1 - Geometry of log-periodic aerial

dipole elements of different lengths — the lengths and spacings between elements forming a geometric progression with common ratio $\tau (< 1)$. The basic geometry is indicated in Fig. 1. Referring to the Fig.

$$\tau = \frac{l_{n-1}}{l_n} = \frac{r_{n-1}}{r_n} = \frac{a_{n-1}}{a_n} \quad (i)$$

where l_{n-1} , l_n , r_{n-1} and r_n are lengths shown and a_{n-1} , a_n are the diameters of the corresponding elements.

A space factor, σ , is defined,

$$\sigma = \frac{d}{2L} = \frac{r_n - r_{n-1}}{2l_n} \quad (ii)$$

and the characteristic angle α is related to τ and σ by

$$\tan \frac{\alpha}{2} = \frac{1 - \tau}{4\sigma} \quad (iii)$$

The operation of the aerial is well-documented.² Briefly, a coaxial feeder input energises a balanced feeder boom along which half-wave length dipole elements are arrayed in an alternate manner. Power is radiated by those elements close to resonance and at a particular frequency this comprises a group of about three or four. This 'active' region of the aerial moves up and down the aerial boom as the frequency is varied. The boom is terminated in a short-circuit. The arrangement of coaxial feeder, balanced feeder boom and short circuit termination provides a balun action. Because of the way in which the phase transition between elements is arranged, radiation from the elements is end-fire in the direction of the smaller elements.

The initial design was based on an early study of log-periodic aërials by Carrel,³ in which a number of nomograms are presented relating the aerial parameters for given conditions. Although the analysis is not exhaustive it is sufficient as a starting point from which a prototype aerial can be developed and optimised by experiment.

A combination of τ and σ was chosen to give optimum directivity over the band and to give an acceptable overall size by restricting the number of elements as necessary. The values arrived at are:

$$\begin{aligned}\tau &= 0.93 \\ \sigma &= 0.18 \\ N &= 15\end{aligned}$$

and these give an overall length of about 1 m and longest element overall length of 300 mm.

The design frequency range of the aerial is made wider than required to take account of the end-frequency effects which curtail the active operating range. Near the band edges the 'active' region is reduced to fewer elements and log-periodic operation ceases. Accordingly, the lower frequency limit is made about 10% lower than the lowest frequency of interest and this determines the length of the longest element in the array.

The element diameters are inter-related by the τ factor as seen in (i). It would be impracticable to propose the use of elements, all of different diameters. Three diameters have been chosen which satisfy (i) reasonably closely and the length of the elements appropriately adjusted to compensate for the error by applying the King-Middleton formulae.⁴

The input impedance of the aerial is determined chiefly by the feeder boom impedance which in turn depends on the size and spacing of the feeder booms and the driving point impedances of the elements which load the boom. The terminating short circuit of the boom is not very critical and has only a secondary effect on the pattern performance of the aerial at the lower end of the frequency range. Its optimum position was found by experiment.

The first version of the aerial was built around an air-spaced boom but a second version based on a dielectric-spaced boom was considered because it could give icing protection in the gap between the booms. In the initial design an allowance was made for the lower velocity of propagation in the dielectric and this meant a shorter boom but a wider angle of boom taper.

3. Mechanical construction

The aerial boom is constructed from 3/4 in. square cross-section aluminium alloy tubing separated by nylon spacers in the case of the air-spaced version and a polythene wedge in the case of the dielectric-loaded version. The elements are of the same alloy, circular in cross-section and attached to the boom by threaded bushes and held tight by an anti-slip compound. The bushes facilitate element replacement. The mechanical dimensions of the aerial are listed in Table 1.

A mounting bracket incorporating the short-circuit termination holds the boom together at the back. The front is held and protected by encapsulation in expanded polystyrene.

TABLE 1

Aerial Dimensions

Element number	Element half-lengths (mm)	Element diameters (mm)	Element Spacings airspaced (mm)	Element Spacings polythen (mm)
1	152	12.70	116	97
2	140.5	12.70	108	90.5
3	130	12.70	99	84
4	120	12.70	93.5	78
5	111	12.70	87	72.5
6	103	9.53	80.5	67.5
7	94.5	9.53	75	63
8	87.5	9.53	70	58.5
9	80.5	9.53	65	54.5
10	73.5	9.53	61	50.5
11	71	6.35	56	47
12	65.5	6.35	52	43.5
13	59.5	6.35	48.5	40.5
14	53.5	6.35	44.5	38
15	48	6.35		

The aerial feed input is a standard N-type connect mounted on a small alloy block fitted into the end of one of the booms at the back of the aerial. The coaxial cable passes up the inside of one boom to protect it from mechanical damage and also to shield it electrically. The cable is made off onto the booms via a ferrule as shown in Fig. 2.

The boom is designed so that water may enter and leave freely. Weather protection is provided at the vertex points by the encapsulation of the drive point and by sealing the cable where it enters the connector.

The two versions of the aerial are illustrated in Figs 3 and 4.

The air-spaced and dielectric-spaced aerials weigh respectively 2.3 kg and 2.5 kg.

4. Further design considerations

Some of the more important aspects of the aerial design are considered further in some detail.

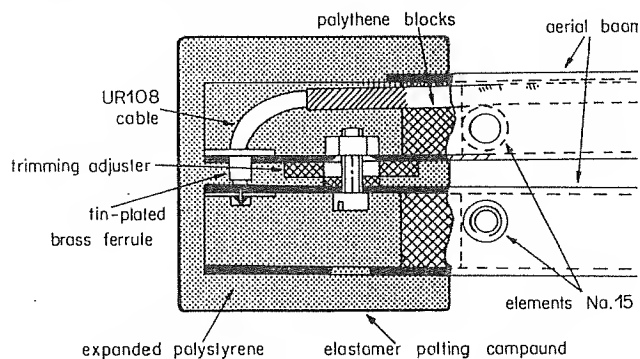


Fig. 2 - Driving point of air-spaced aerial

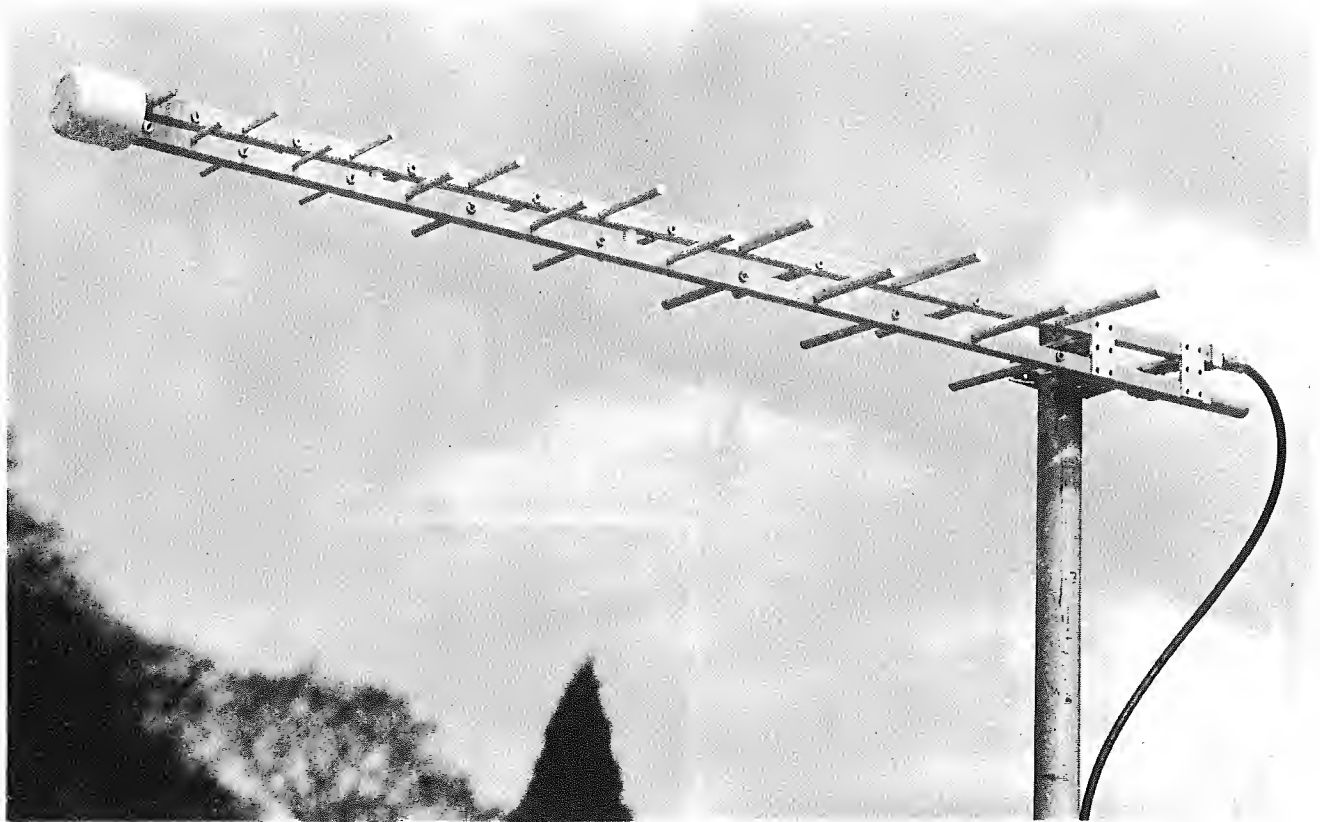


Fig. 3 - Air-spaced ruggedised u.h.f. log-periodic aerial shown for horizontal polarisation

4.1. Boom taper

The manner in which the dipole elements are attached to the boom inevitably means that there is a transverse displacement between them. With the feeder booms parallel, the transverse displacement expressed in terms of wavelengths appropriate to the frequency associated with a dipole element, would vary along the boom. By opening out the boom at the back of the aerial to maintain the transverse displacement constant in terms of wavelengths, a better match of feeder boom impedance to the driving-point impedance of the individual elements is achieved. This results in a better coupling of power into the elements.

Evans⁵ has demonstrated the effects of excessively increasing the transverse displacement of the elements on log-periodic performance. The resistive part of the driving-point impedance of an element is shown to remain substantially unchanged until the displacement reaches 0.03λ . Because the aerial input impedance can be considered to be essentially made up from those elements comprising the active region at any one frequency and which are close to resonance, it will be affected little by displacements up to 0.03λ . The radiation pattern is also affected by the transverse displacement; the main beam tends to slew round and the sidelobes increase in amplitude.

The optimum degree of taper was found by experiment and the transverse displacement for this condition closely follows the τ relationship. The following results were obtained:

$$\text{Air-spaced aerial, } \frac{D}{\lambda_{\max}} \approx 0.03$$

$$\text{Polythene-spaced aerial, } \frac{D}{\lambda_{\max}} \approx 0.04$$

where $2D$ is the transverse displacement between elements.

The effect of the larger D/λ_{\max} in the polythene-spaced aerial is just noticeable in the pattern and match at 450 MHz but this is not disturbing.

4.2. Element length compensation

In the initial design, the calculation of element lengths by applying the τ factor and the King-Middleton formulae takes no account of the mutual impedances between the elements in the array. Some compensation is required especially at the high-frequency end of the aerial where dimensions are generally more critical.

The final element lengths were determined experimentally by making small adjustments to the lengths of the nine most critical elements, and monitoring the match conditions at the same time.

The element lengths are the same for both the air-spaced and the dielectric-spaced versions of the aerial.

4.3. Drive-point

If the input impedance characteristic as a function of

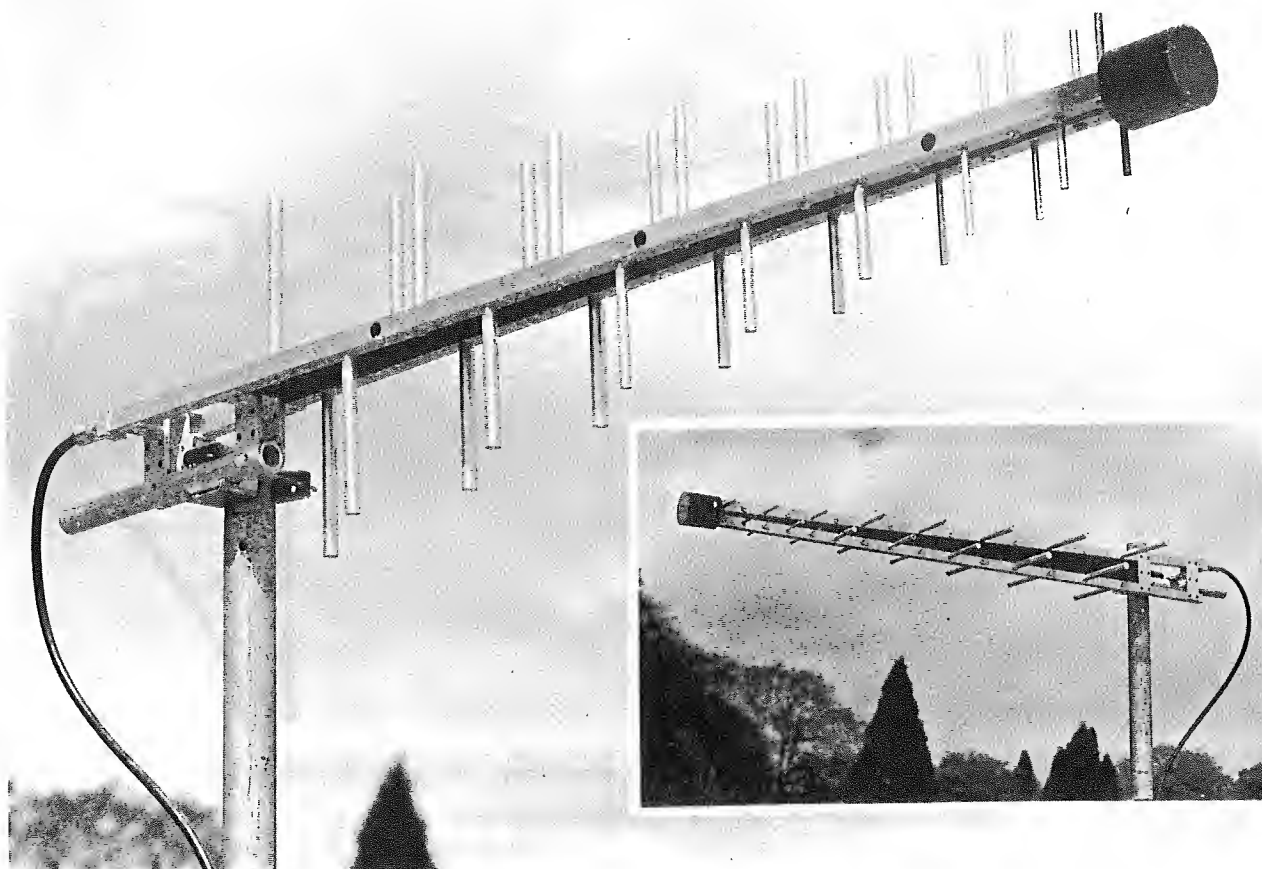


Fig. 4 - Polythene-spaced ruggedised u.h.f. log-periodic aerial shown for vertical polarisation (inset horizontal polarisation)

frequency were represented on a Smith Chart, it would appear as a small group, of points, lying within a circle, over the working frequency range. The impedance characteristic is optimum when the centre of this circle lies at the centre of the Smith Chart, i.e. at the point of zero reflection. This can be adequately achieved by adding a small amount of shunt susceptance to the feeder boom in the region of the drive-point. The drive-point of the air-spaced aerial is shown in Fig. 2. A small slotted polythene adjuster is used to optimise the aerial match.

The drive-point also forms part of a balun arrangement whereby the unbalanced currents carried by the coaxial feeder are fed as balanced currents along the feeder boom. This transition is satisfactory provided the gap between the boom at the drive-point is kept small.

4.4. Dielectric loading

The addition of a dielectric medium into the gap between the feeder booms is designed to provide some degree of icing protection because it effectively bridges the area where the electric field is strongest and which is most susceptible to icing. The effect of the dielectric on the electrical performance of the aerial can be summarised as:

- (i) The increased dielectric constant of the feeder boom

dielectric lowers the characteristic impedance of the feeder boom transmission line. To preserve the input impedance of the aerial, the boom must be tapered more to compensate.

- (ii) The velocity of wave propagation in the feeder boom transmission line is reduced and the phase transition between the driving points of the dipole elements is altered. The spacings between the elements along the boom must be reduced to compensate. Although the driving points of the dipole elements lie on the feeder boom transmission line, the elements themselves radiate in air. The spacing of the elements along the boom has, therefore, to be reduced by a velocity factor which has a value between the relative velocity of propagation of the dielectric and unity.

A prototype aerial was constructed with a velocity factor of 0.80. Several polythene wedges with different tapers were tried in turn, located in the feeder boom. An optimum wedge was found by examination of the aerial match and radiation pattern.

The prototype was used to investigate the effect of varying the velocity factor. By moving the dipole elements along the boom by one step at a time and inserting extra elements of suitable lengths as necessary, the velocity factor

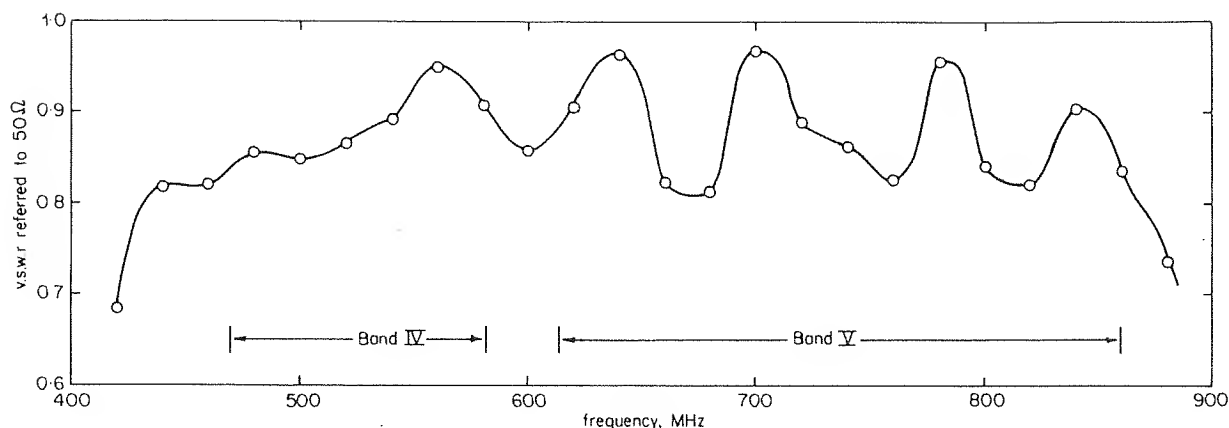


Fig. 5 - Typical v.s.w.r. of air-spaced aerial referred to 50Ω

can be effectively changed if the aerial performance is examined over a slightly different frequency range. In this way the velocity factor was varied between 0.67 and unity in five operations. A value of 0.85 was chosen because it gave the aerial a satisfactory match consistent with reasonably undistorted radiation patterns.

4.5. Weather-proofing

Complete protection of the aerial by means of a radome was not favoured because of the excessive increase in windloading area which would result.

The most vulnerable part of the aerial, the drive-point, is protected by an expanded polystyrene moulding which encloses the whole of the end of the aerial beyond the last element. The boom is designed so that water can enter and leave freely although if necessary the boom could be fitted with expanded polyurethane foam to seal it completely.

The extra shunt susceptance attributed to the end-encapsulation has to be allowed for in the aerial adjustment prior to moulding.

The moulding is coated with a sealant which forms a resilient surface and finally painted with a vinyl plastic enamel.

Tests to simulate the effects of heavy rain reveal that the impedance match is generally only worsened 1–2%. The performance has not been examined under severe weather conditions. It would be practicable to install a heater element in one of the hollow sections of the boom to give increased weather protection.

5. Measured performance

The aerial performance has been assessed in terms of the impedance match to 50Ω, the radiation pattern in both E- and H-planes under normal and cross-polarization conditions and the gain relative to a half-wave dipole. Measurements were made over the u.h.f. bands IV and V.

5.1. Impedance match

Impedance match measurements were made using a complex impedance bridge. In both versions of the aerial the v.s.w.r. is better than 0.8 over the Bands IV and V. The results of the measurements, in magnitude only, are reproduced in Figs. 5 and 6. The performance achieved is considered adequate for transmitting purposes at stations with present-day transposers and splitter transformers.

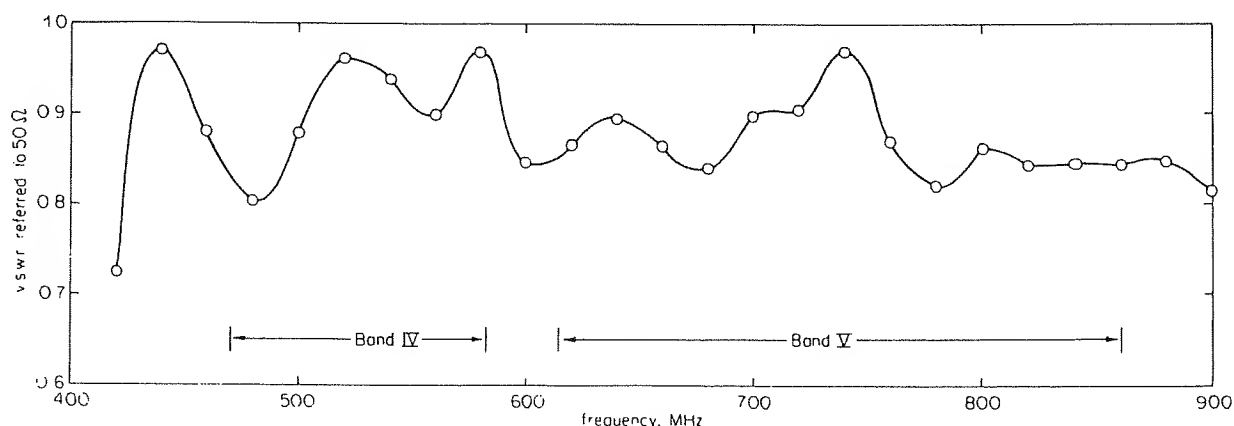


Fig. 6 - Typical v.s.w.r. of polythene-spaced aerial referred to 50Ω

5.2. Radiation patterns

The radiation patterns were plotted on automatic equipment, the aerial under test being the transmit aerial, which is rotated and the received signal measured on a 'horn' aerial fixed some distance away. The distance between the aerials is determined by minimising the effects of ground reflections. The results measured at 100 MHz intervals for both the air-spaced and polythene-spaced aerials are shown in Figs. 7 – 11 and Figs. 12 – 16 respectively. Minor departures from symmetry are neglected because they are generally small. There is, however, a noticeable slew of about 2° in the main lobe of the h.r.p. of the polythene-spaced aerial at 450 MHz but this is out of the Band.

In the region of the main radiating lobe of the pattern, accuracies of ± 0.5 dB can be claimed but in the minor lobe area there are several factors which introduce greater inaccuracies:

- (i) the setting-up of the transmit and receive aerials by line-of-sight,
- (ii) the compromise necessary to minimise the effect of ground reflections,
- (iii) the presence of interfering signals e.g. television transmissions.

The radiation patterns of the two versions of the aerial are very similar. The polythene-spaced version has a slightly wider beamwidth because of the greater transverse displacement of the dipole elements. The beamwidths and worse minor lobe levels are tabulated in Tables 2 and 3.

The CCIR templet for the recommended minimum directivity of a u.h.f. receiving aerial⁶ is largely met by the E-plane pattern but is transgressed by the H-plane pattern in the main lobe region. For field-strength measurement applications this is satisfactory and if for any reason a

greater directivity were desired, two aerials side-by-side would suffice.

There is no transgression of the templet as far as minor lobe radiation is concerned.

Measurements have also been made to check the cross-polarisation performance when signals are received from aerials on the opposite polarisation. The CCIR recommendation is that there should be more than 20 dB protection, relative to the peak of the main lobe, on all angles of orientation.⁷ This is substantially achieved for both versions of the aerial.

5.3. Gain

The aerial gain relative to a half-wave dipole has been computed from the radiation patterns. The results are shown in Tables 2 and 3 for both versions. The values quoted include the loss associated with the cable in the boom and can, therefore, be taken as referred to the input connector at the back of the aerial. The gain remains approximately constant through the Bands IV and V.

6. Conclusions and discussion

Two versions of a u.h.f. log-periodic aerial have been developed, both substantially fulfilling the electrical requirements specified; one has a greater protection against icing. Mechanically, the aerial has been made rugged but not excessively heavy. The dipole elements are specifically designed to be a 'weak link' and are replaceable units. The end-encapsulation provides a substantial degree of protection to the drive-point and can be replaced if damaged.

The versatility of such an aerial means that it can not only be used for transmitting arrays and for field-strength measuring purposes but possibly in RBL arrays also. If produced in sufficient quantities, unit cost could be comparatively low.

TABLE 2

Air-spaced Aerial Performance

Frequency MHz	Half-power beamwidth degrees		Gain dB rel $\lambda/2$ dipole at aerial input	Minor lobe radiation dB below maximum field	
	E-plane	H-plane		E-plane	H-plane
450	± 28	± 35	7.8	31.5	26.5
500	± 27	± 35	8.0	37.0	30.0
550	± 27	± 35	8.3	31.0	28.0
600	± 26	± 34	8.3	32.0	30.0
650	± 26	± 32	8.4	38.0	34.5
700	± 27	± 35	8.4	28.0	25.0
750	± 27	± 35	8.0	24.0	24.5
800	± 26	± 33	8.0	28.0	26.0
850	± 26	± 35	8.0	29.0	27.5
900	± 25	± 35	8.0	26.0	24.0

TABLE 3

Polythene-spaced Aerial Performance

Frequency MHz	Half-power beamwidth degrees		Gain dB rel $\lambda/2$ dipole at aerial input	Minor lobe radiation dB below maximum field	
	E-plane	H-plane		E-plane	H-plane
450	± 28	± 35	8.0	24.0	25.0
500	± 28	± 35	8.1	33.0	31.0
550	± 27	± 35	8.2	29.0	30.0
600	± 26	± 35	8.2	32.0	27.0
650	± 25	± 34	8.3	31.0	33.0
700	± 26	± 35	8.3	27.0	28.0
750	± 27	± 36	7.8	27.0	23.5
800	± 28	± 34	7.8	26.0	22.5
850	± 28	± 37	7.8	30.0	22.5
900	± 29	± 41	7.3	23.0	22.0

The possibility of using the ruggedised log-periodic aerial in transmitting arrays and receiving arrays will be the subjects of future Reports.

7. References

1. EATON, J.L. and THODAY, R.D.C. 1969. A UHF log-periodic receiving aerial. BBC Research Department Report No. 1969/20.
2. JORDON, E.C. and BALMAIN, K.G. 1968. *Electromagnetic waves and radiating systems*, 2nd ed. Englewood Cliffs, D.J., Prentice Hall, 1968, pp. 609 ff.
3. CARREL, R. 1961. The design of log-periodic dipole antennas. *I.R.E. int. Conv. Rec.*, 1961, 9, 1, pp. 61 — 75.
4. KING, R.W.P. 1956. *Theory of linear antennas*. Cambridge, Mass., Harvard University Press, 1956.
5. EVANS, B.G. 1969. The effects of transverse displacements on log-periodic dipole arrays. *Trans. Antennas Propag.*, 1970, AP-18, 1, pp. 111 — 128.
6. Directivity of antennae in the reception of broadcast sound and television. CCIR Rec. 419, Geneva 1967.
7. Recommended characteristics for collective and individual antenna systems for domestic reception of signals from terrestrial transmitters. CCIR Rep. 482, Delhi 1970.

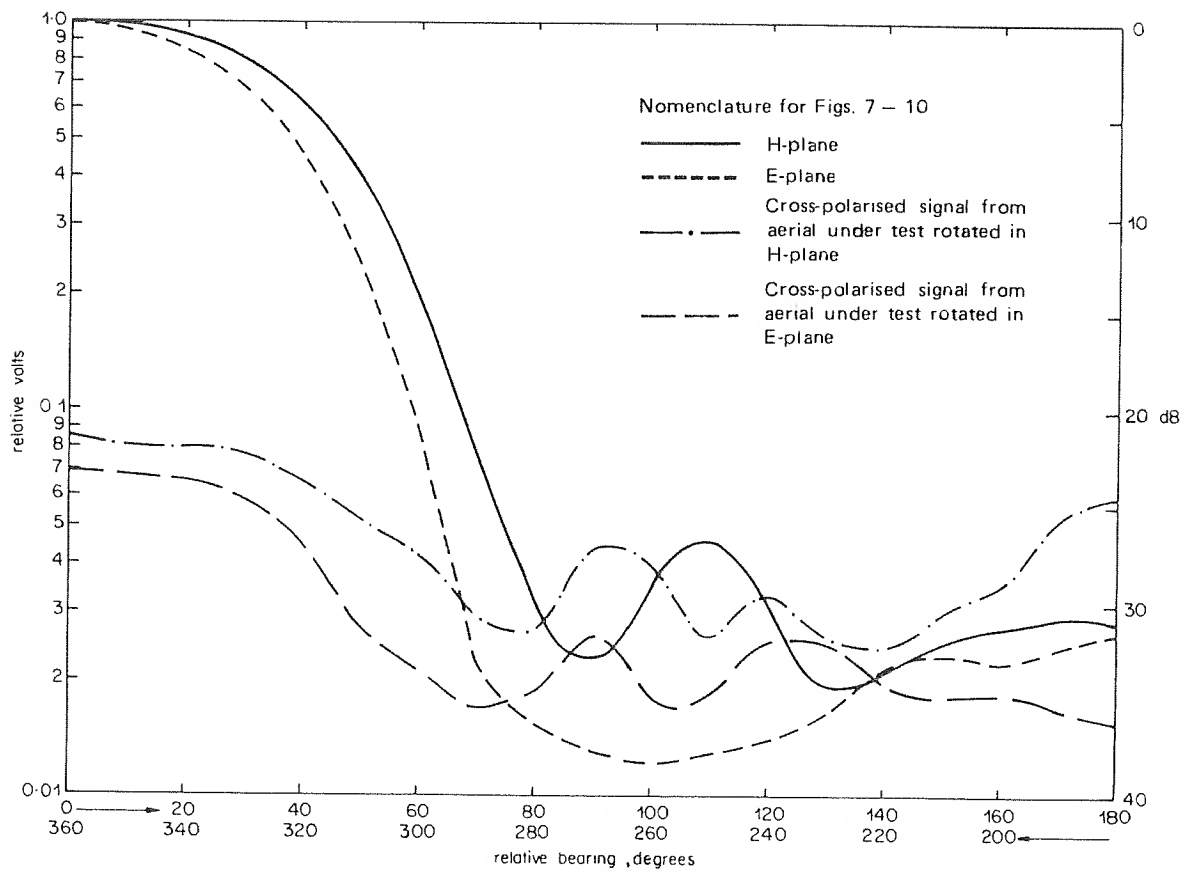


Fig. 7 - Radiation patterns of air-spaced aerial; 450 MHz

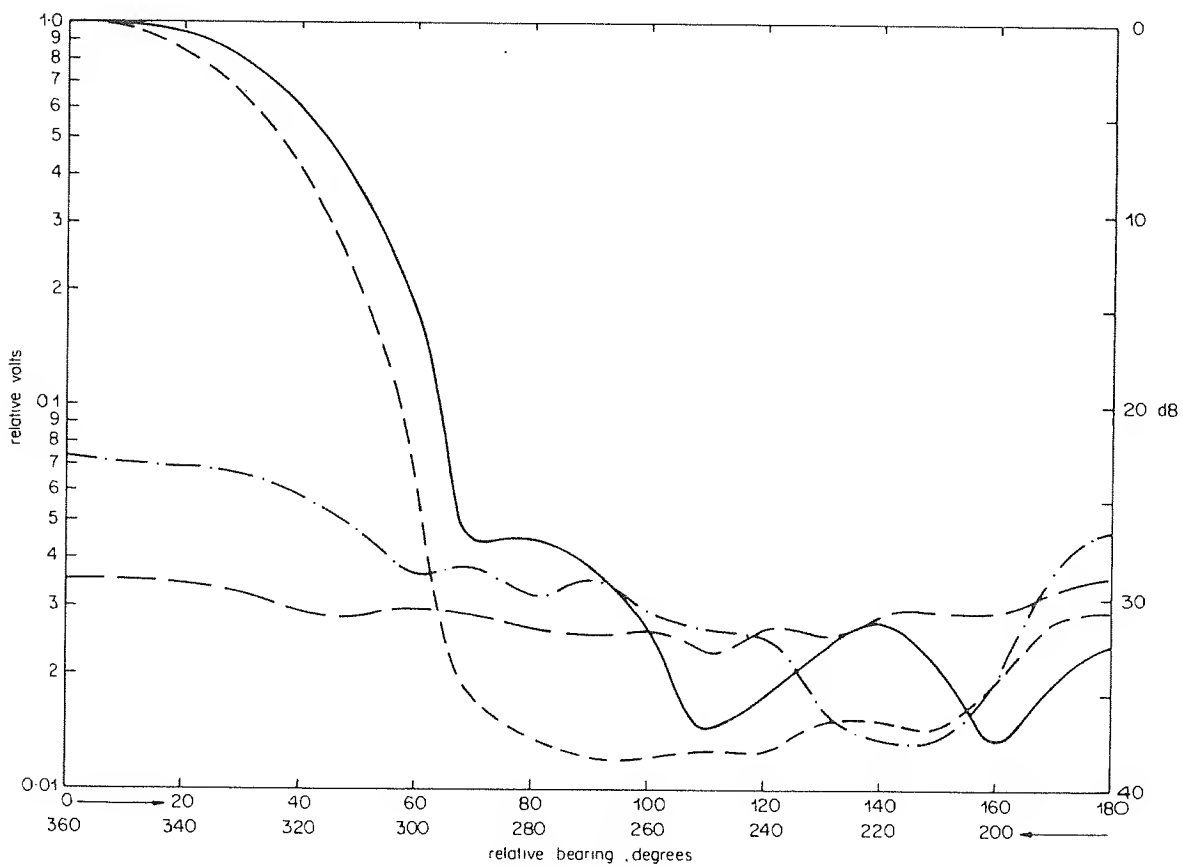


Fig. 8 - Radiation patterns of air-spaced aerial: 550 MHz

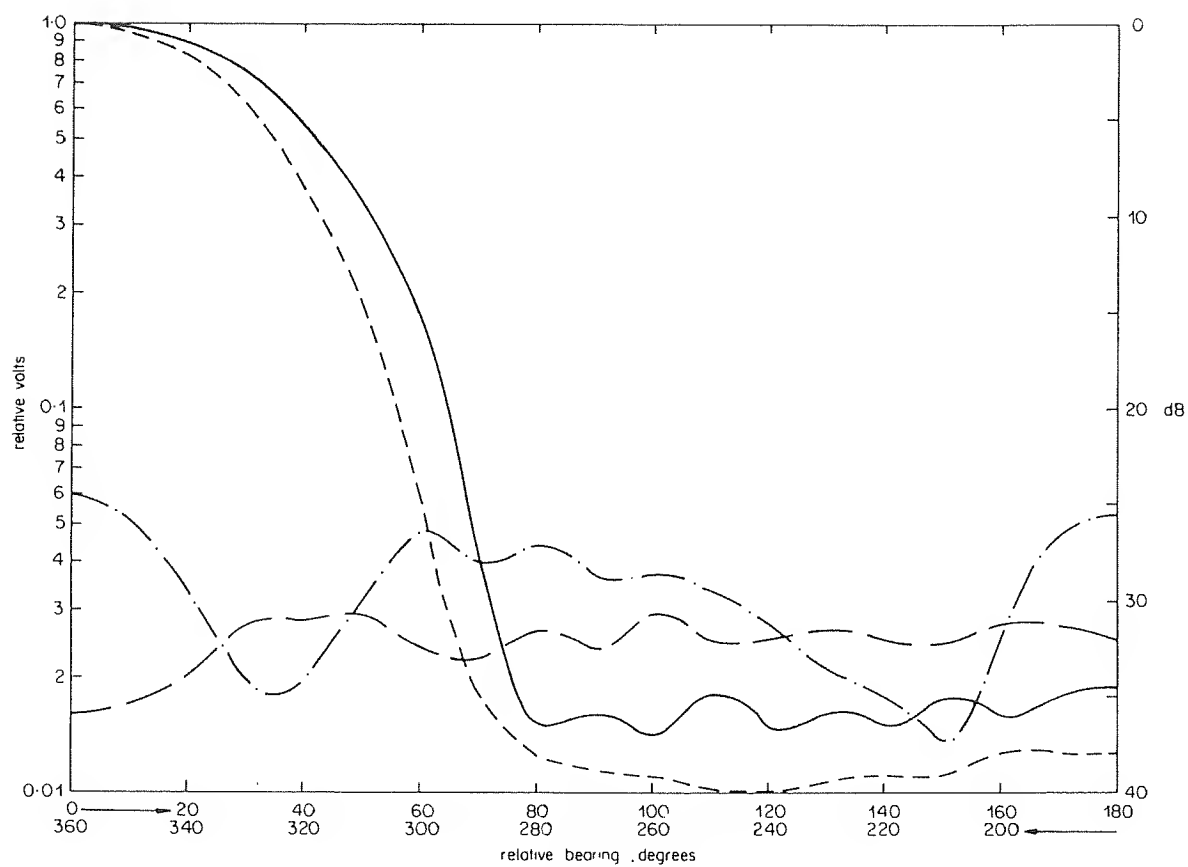


Fig. 9- Radiation patterns of air-spaced aerial: 650 MHz

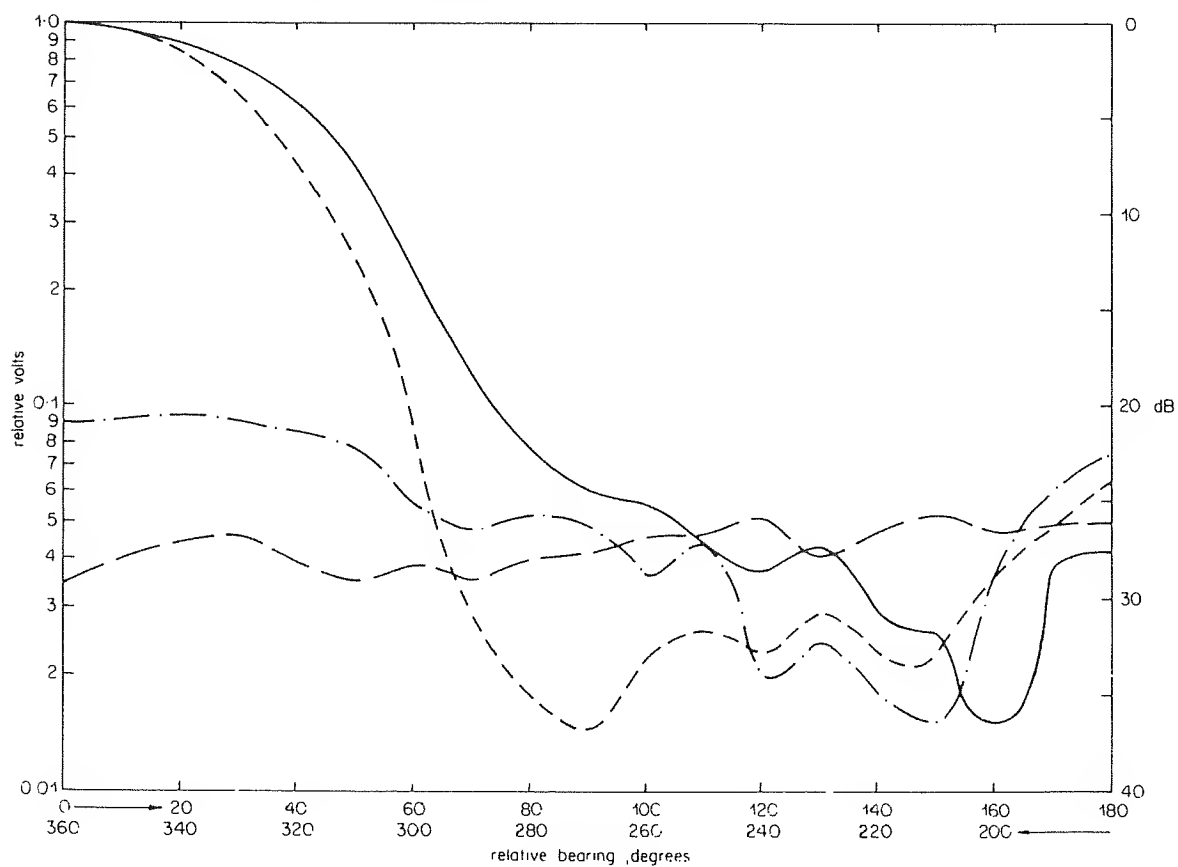


Fig. 10- Radiation patterns of air-spaced aerial: 750 MHz

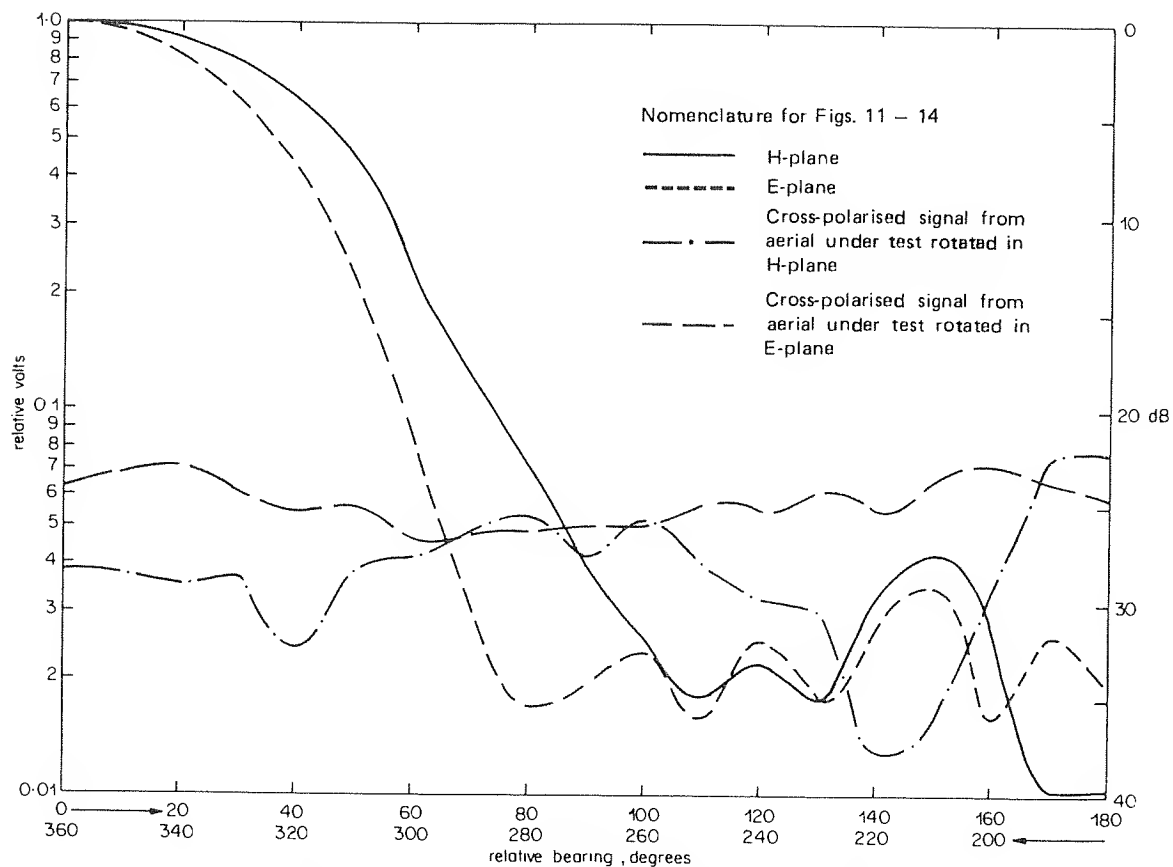


Fig. 11 - Radiation patterns of air-spaced aerial: 850 MHz

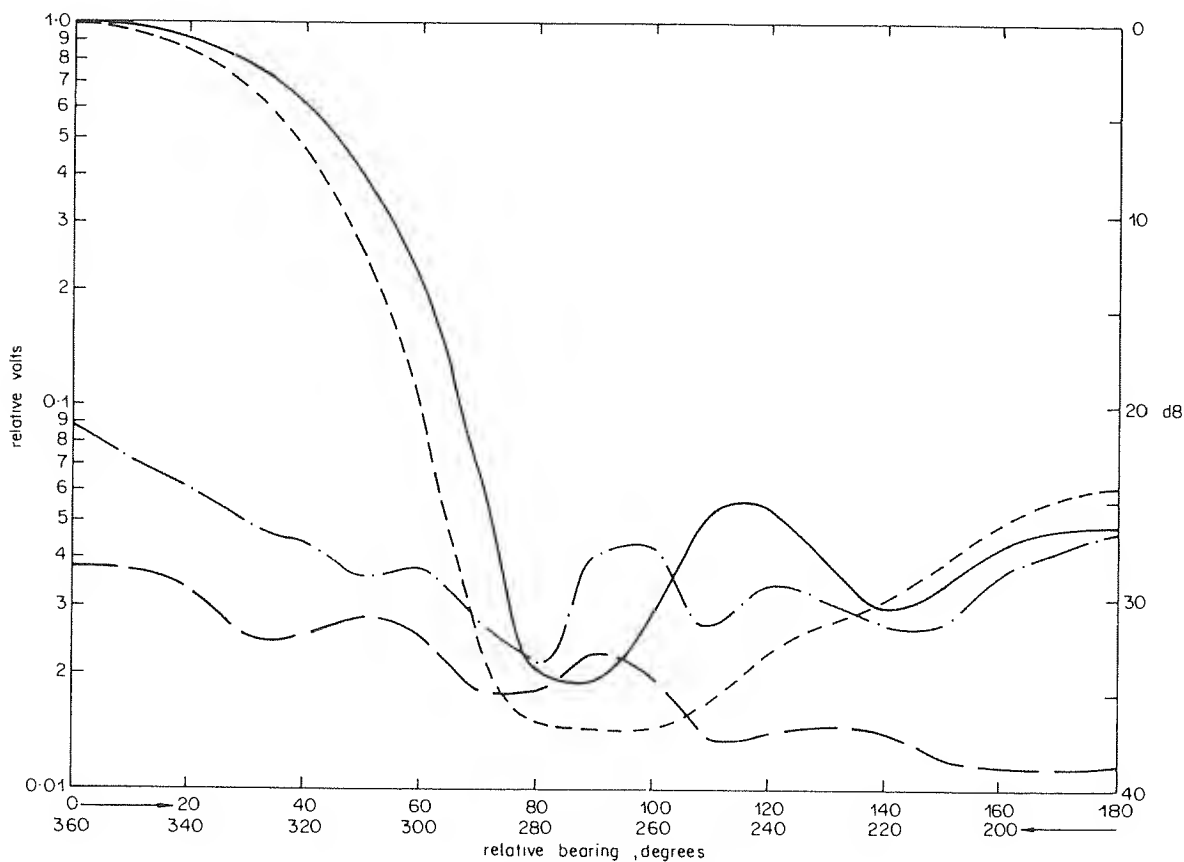


Fig. 12 - Radiation patterns of polythene-spaced aerial: 450 MHz

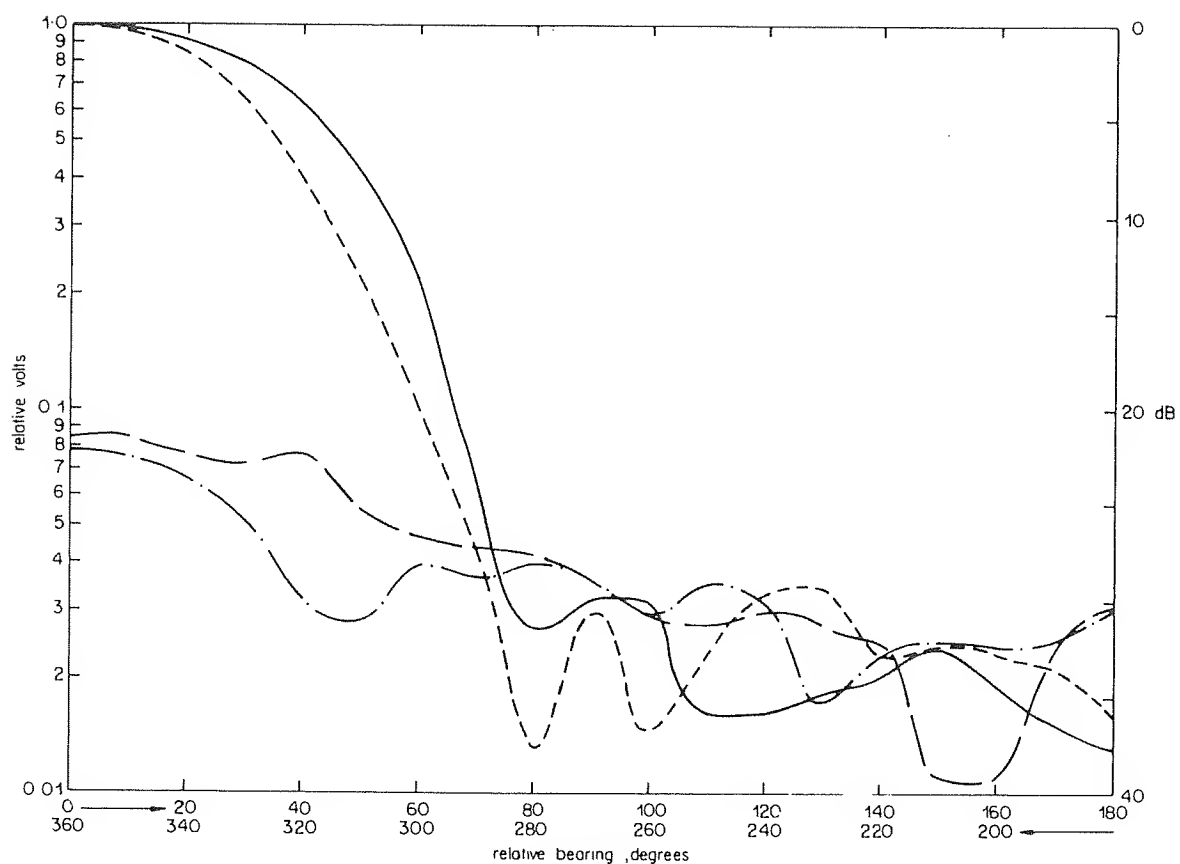


Fig. 13 - Radiation patterns of polythene-spaced aerial: 550 MHz

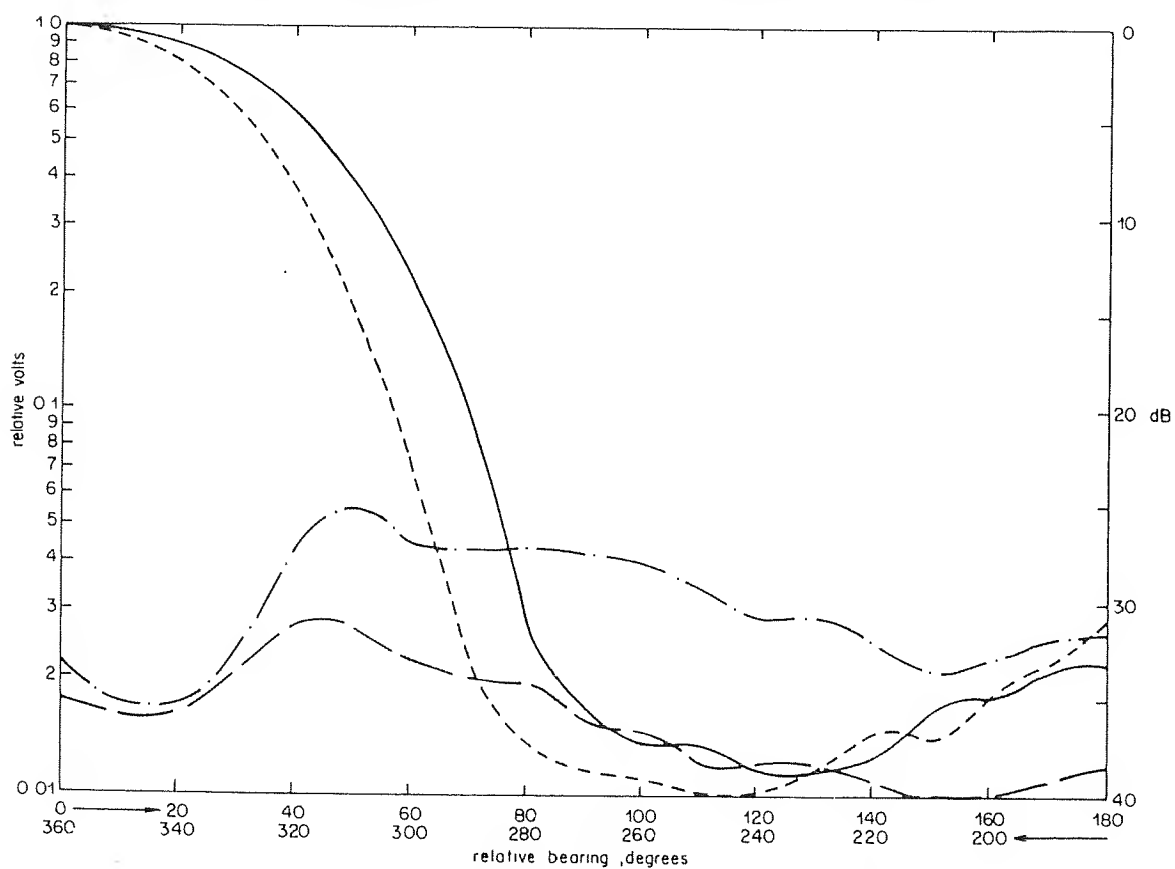


Fig. 14 - Radiation patterns of polythene-spaced aerial: 650 MHz

